PIV Investigations of LSB Flames

Need to Obtain More Details of the Development of LSB Flowfields

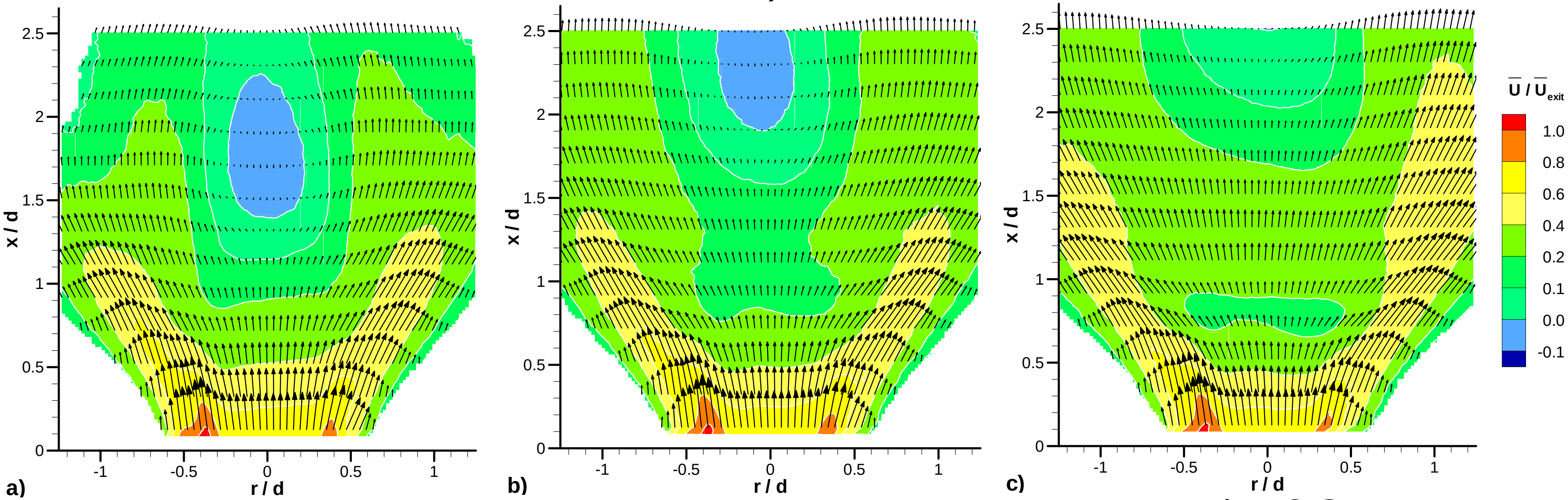
- **Simulation of air-jet LSB in progress**
  - yet to achieve stable solution due to complexities of interaction between core flow, swirling flow and freely propagating flame
- **Previous LDV data not sufficiently extensive for direct comparison**
  - needs better characterization of outer swirling flow region, self-similarity, downstream recirculation and swirl number effects
- **Rectified swirl number definition for air-jet LSB**
  - Previous definition derived from equation for a special case
  - New definition compatible with definition for vane LSB

$$S = \frac{\pi R_e R}{A_j}\left(\frac{\dot{m}_j}{\dot{m}_{total}}\right)^2$$

Re **= burner radius** ***R*** **= injector radius**
Aj **= total area of the swirl jets**
$\dot{m}_j$ **= total mass flow rate of swirl**
$\dot{m}_{total}$ **= total mass flow rate of reactants**

Downstream Flow Recirculation Weakened by Combustion Heat Release

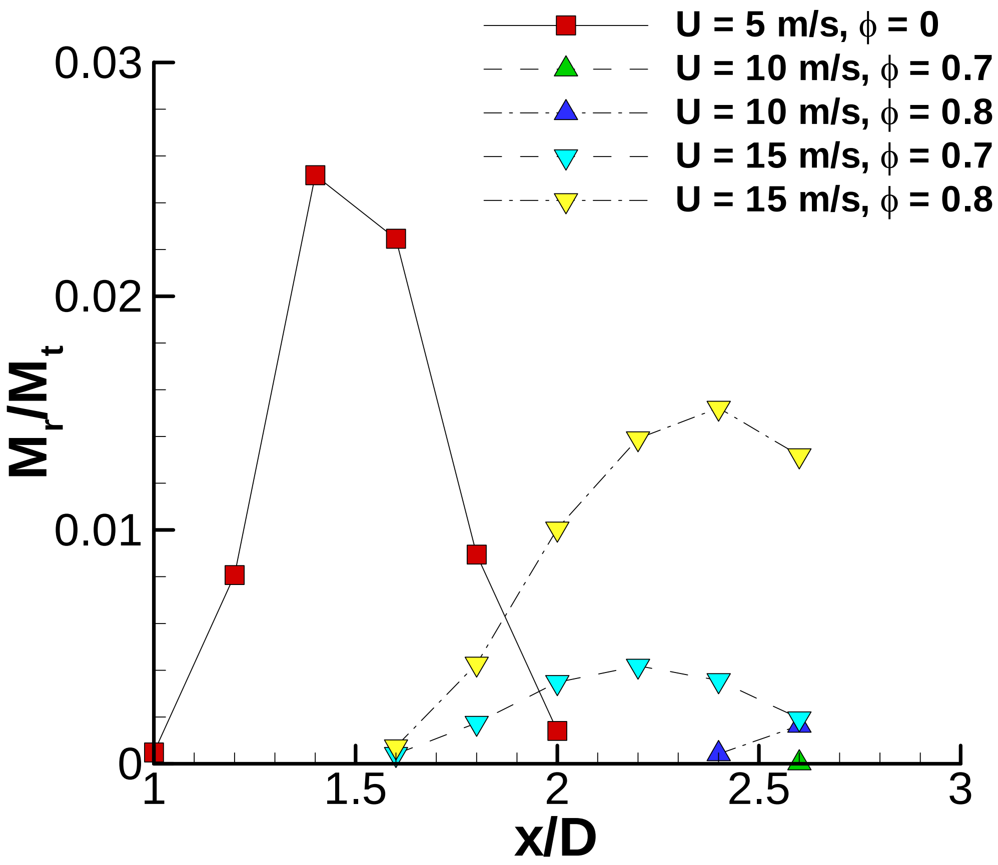
S=0.85 and Re≈37,000 U ≈10.5 m/s



$\phi = 0$ $\phi = 0.7$ $\phi = 0.8$

- PIV with a large field of view shows the formation of a downstream recirculation bubble at x/D > 1
- Downstream recirculation does not affect flame brushes in the upstream region (x/D < 1)

Quantifying Recirculation Strength



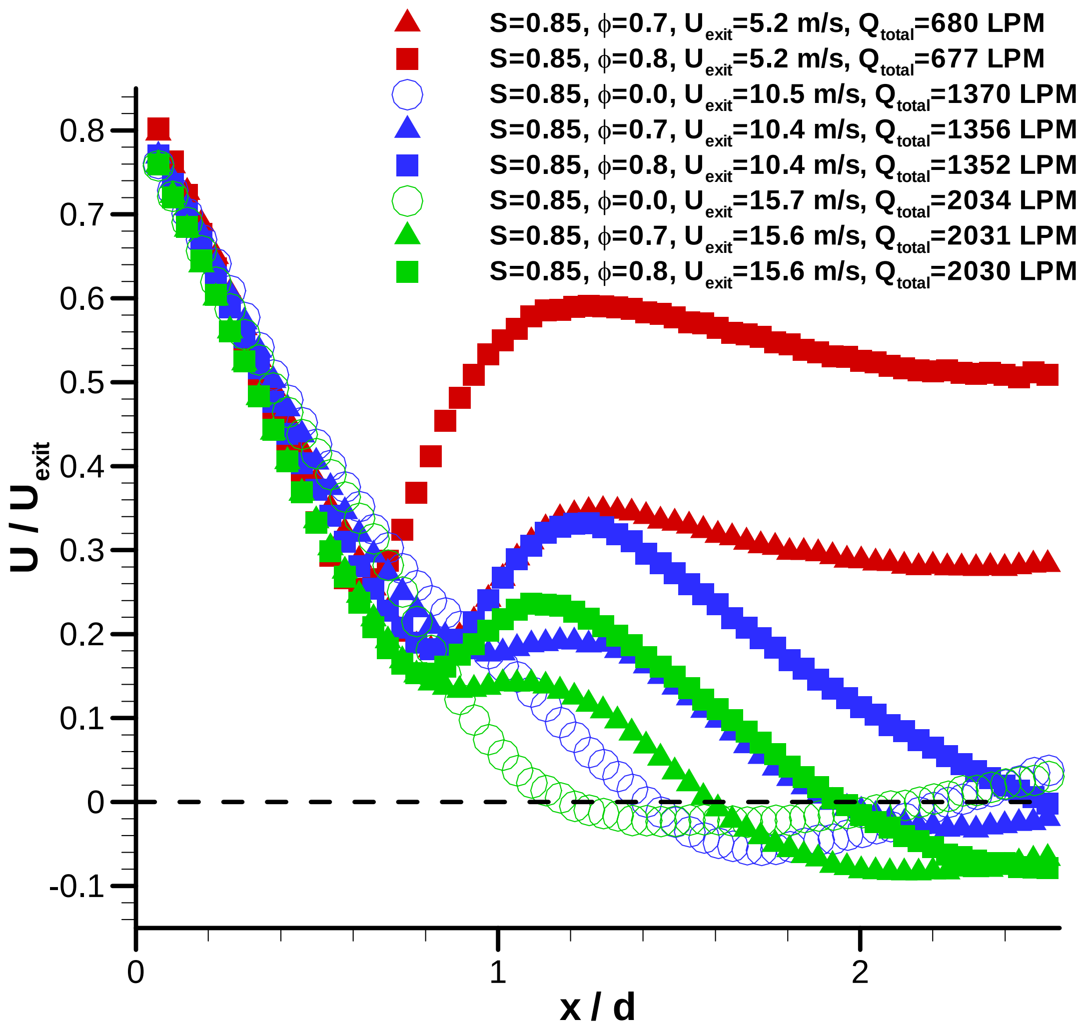
- **Reversed mass flow rate**

$$M_r = \int_0^{y_0} 2\pi\, y \rho U dy$$

y_0 = zero velocity boundary

- **Recirculation strength increases non-linearly with S**
- **Typical values of M_r/M_t in LSB are 10 orders of magnitude lower than in typical high swirl burners (up to $M_r/M_t = 2$)**
- **Provides another critical test for simulation**

Similarity Found In LSB Flowfield



- Normalized centerline profile shows consistent linear decay of mean axial velocity at the exit
- Explains why flame brush remains stationary with increasing U
- New and important insight on the mechanism of low-swirl flame stabilization

Studies of Thermal/Diffusive Instability in Turbulent Flames

Flame Front Instabilities in Turbulent Flames

- **Wrinkling introduces flame front curvatures, as well as flame front compression or stretch**
- **Local flame speed on the flame fronts, *s*, is proportional to stretch via the relationship**

$$s/s_L = 1 - Ma\ Ka_L$$

Ma **is the Markstein number**

Ka_L **is the Karlovitz number for a local stretch rate**

- **Studies of flames with moderate turbulence show thermal/diffusive instabilities and hydrodynamic instabilities either dampen or promote flame wrinkle formation**
- **Quasi-steady DNS studies (Im and Chen) suggest impact of thermal/diffusive instabilities diminishing at frequencies > 200 1/sec**

Investigate the Significance of Thermal/Diffusive Instability

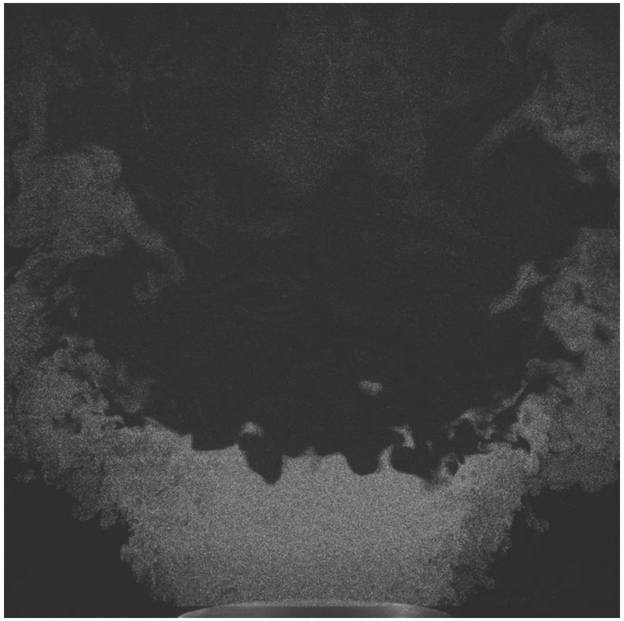
- **How chemistry affects the flowfield has yet to be addressed in complex flame configurations**
  - Previous studies involved flame interacting with a single large vortex or at relatively low turbulence
- **Exploit the unique capability of low-swirl burner to investigate systematically nine H_2, CH_4 and C_3H_8 flames**
  - $S = 0.8$, $U_o = 5 - 15$ m/s, $\phi_{H2} = 0.3$ $\phi_{CH4} = 0.8$ & $\phi_{C3H8} = 0.75$
- **Safety concerns on burning pure H_2 limited the experimental conditions to low to moderate turbulence**
  - Still relevant based on statistical argument
    $57 < u'/l_x < 210$ sec^{-1} for $5 < U_o < 15$ m/s
    comparable to eddy turnover frequency $s_L/d_{L=}$ 300 sec^{-1}

Diagnostics and Analysis

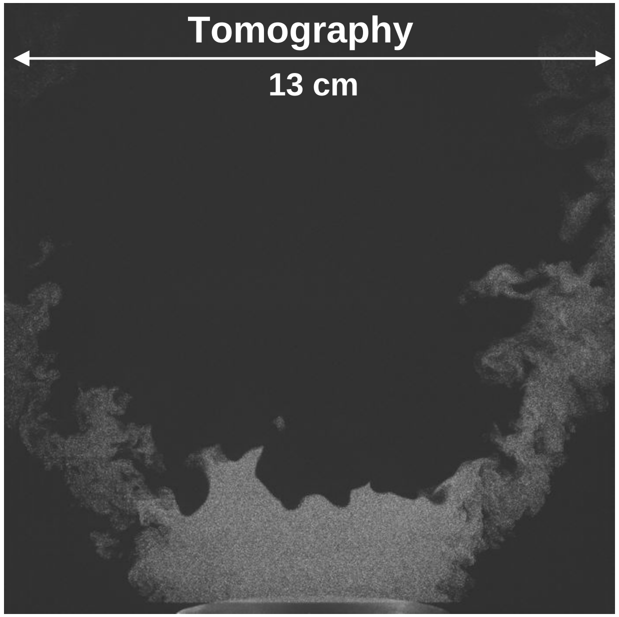
- Experiments completed
  - PIV (448 image pairs)
    - Large field of view (13 by 13 cm)
    - Conditioned velocities using oil aerosol
    - Unconditioned velocities using refractory seeds OH-PLIF (200 images)
    - Smaller field of view (3 by 3 cm)
- Analysis
  - Mean and rms flowfields (complete)
  - Displacement flame speed (complete)
  - Flame front curvature distributions (in progress)

Flame Wrinkle Structures at U_o = 5 m/s, u'/l_x = 57 sec^{-1}

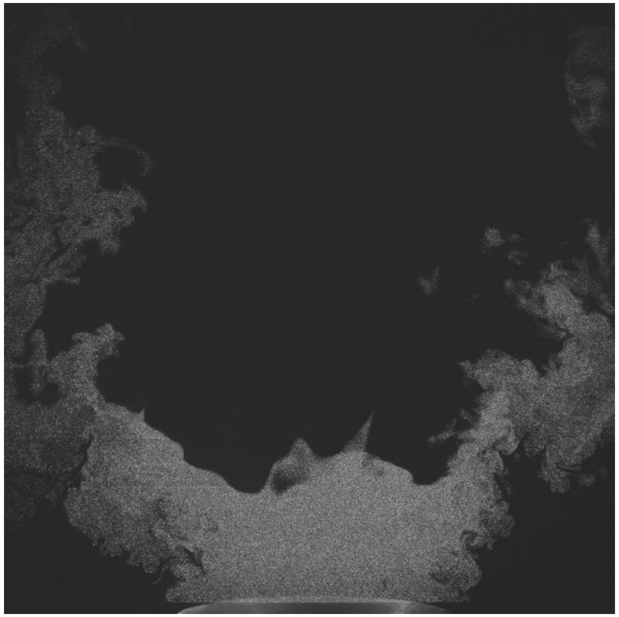
H_2 , ϕ = 0.3, Le = 0.33

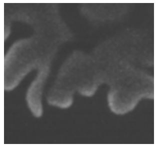


CH_4, ϕ = 0.8, Le $\approx$ 1

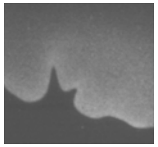


C_3H_8, ϕ = 0.75, Le = 1.85

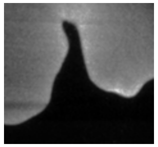




OH-PLIF



3 cm



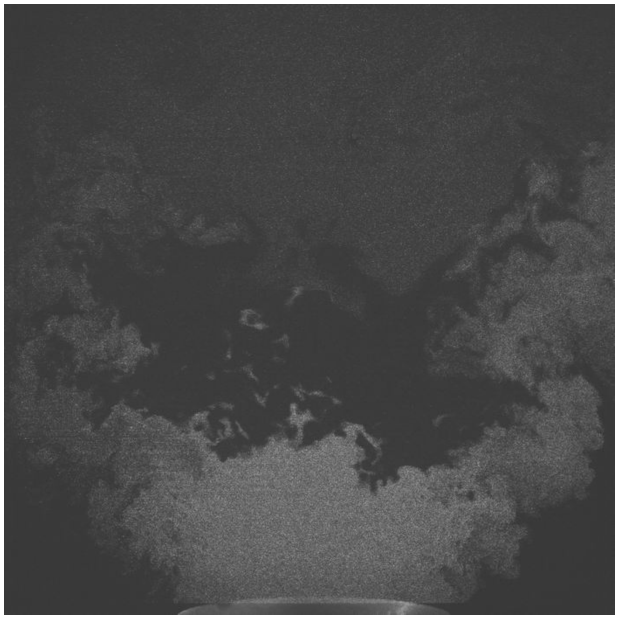
- Difference in flame wrinkle structures readily observable

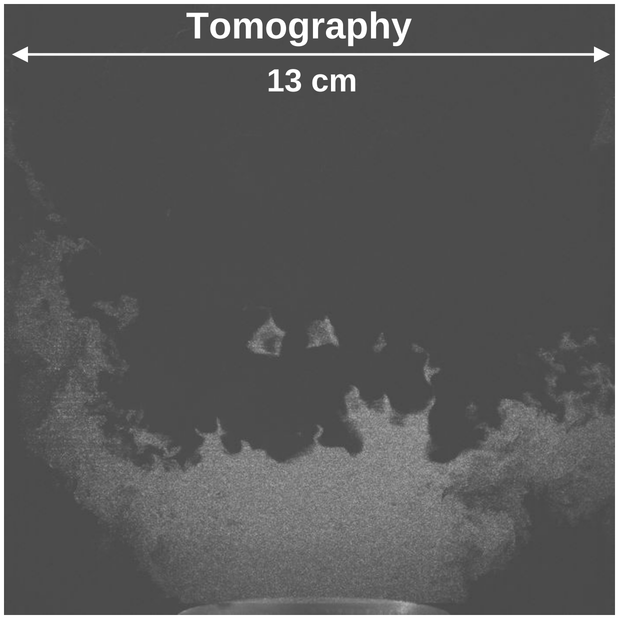
Flame Wrinkle Structures at $U_o = 15$ m/s, $u'/l_x = 210$ sec^{-1}

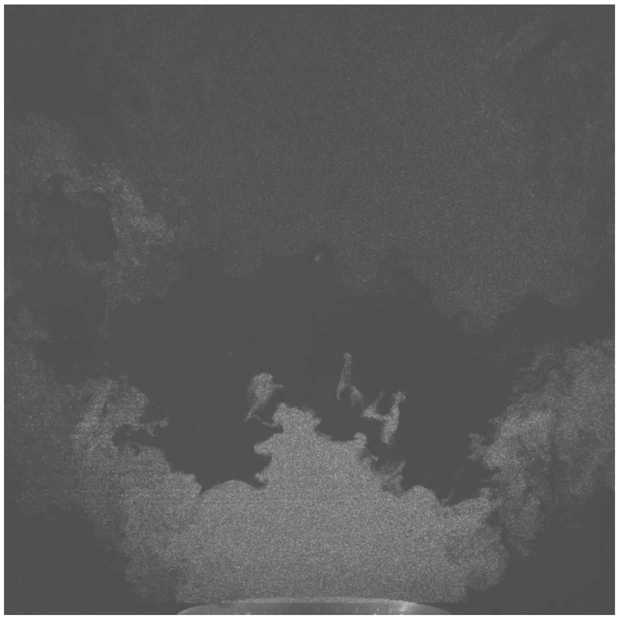
H_2 , $\phi = 0.3$, Le = 0.33

CH_4, $\phi = 0.8$, Le ≈ 1

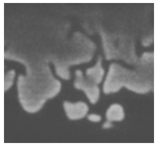
C_3H_8, $\phi = 0.75$, Le = 1.85







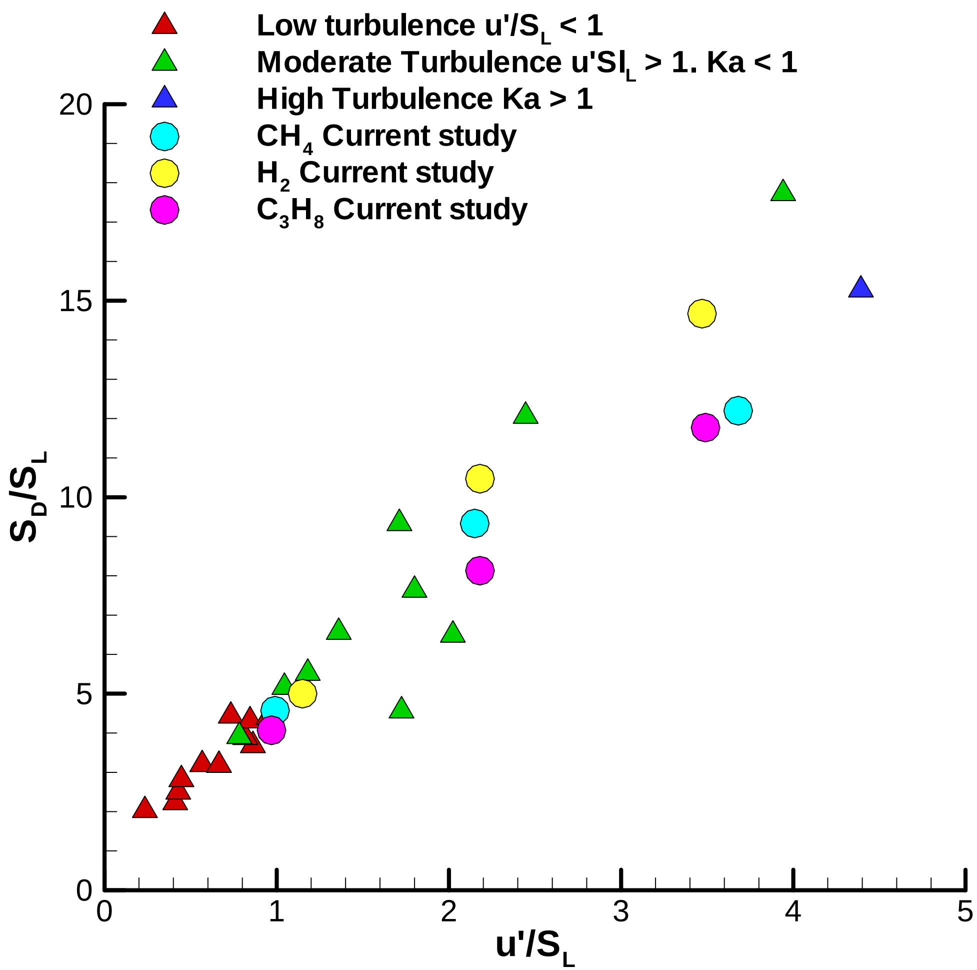
OH-PLIF



3 cm

- Differences in flame wrinkle structures persist

Small Differences Found in Displacement Flame Speeds, S_D, of H_2, CH_4 and C_3H_8 Flames



- PIV data obtained using oil aerosol determine flame brush positions, S_D, and u'
- S_D for all nine flames consistent with those obtained previously for CH_4
- Differences in flame zone divergence implies possible effects on S_c